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OPERATION GREENHOUSE

SCIENTIFIC DIRECTOR'S REPORT
VOLUME II
PART III
EVALUATION OF PROGRAMS 3 TO 6 AND 8

NUCLEAR EXPLOSIONS

1951

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Evaluation of Programs 3 to 6 and 8

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THE SCIENTIFIC DIRECTOR'S REPORT

Volume II

Part III

Evaluation of Programs 3 to 6 and 8

Approved by

ALVIN C. GRAVES
Scientific Director

Los Alamos Scientific Laboratory
Los Alamos, New Mexico

April 1953

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Chapter 1

Program 3, Blast Damage to Structures

The test of structures as Program 3 in Operation Greenhouse was the most comprehensive ever undertaken. In Operation Sandstone there had been tests of shelters and model structures of various shapes, but without instrumentation to measure blast pressures and structural behavior. In planning for Greenhouse, there was sufficient time for orientation and planning of participants at an early meeting. Alvin C. Graves, the Scientific Director, was emphatic in stating that measurements of transient effects must be made even though it had been considered to be impracticable in Sandstone. Furthermore, it was the view of the Joint Proof Test Committee, of which Graves was a member, that tests should be planned so as to provide methods of prediction of damage and design criteria that would be generally useful. To this end arrangements were made for all test proposals to be reviewed by the Technical Evaluation Panel, comprised of outstanding consultants in this field. As a result of their initial reviews and suggestions, a well integrated program was developed for submission to the Research and Development Board (RDB). The RDB approved inclusion of 14 test projects requiring 26 structures. Two of these were composite to permit exposure of several types of construction in each building. The preliminary estimated cost was $3,957,306, and the final cost was approximately $6,000,000. Late in the period of preparation for Greenhouse, the Office of Civil Defense of the National Security Resources Board requested permission to include a project on the testing of windows and glazing prepared jointly with the Public Buildings Service. This was agreed to, but time did not permit a very satisfactory test.

Consistent with the desire to make the test really useful, intensive efforts were made in the preparatory stage. Predictions of blast loading of buildings were developed, using all the available data from shock-tube tests and theory. Similarly, analytical methods of predicting response were derived. As a result of this work, structures were located at the proper distance, and the necessary ranges of transient measurements were established. The preparation for accomplishment of these measurements was a tremendous undertaking. The Sandia Corporation was requested by the Scientific Director to make the measurements of transient blast pressures at selected points on buildings and the transient accelerations and displacements of the structural elements in response to the blast loading. It was necessary to select and adapt the best available equipment for measuring and recording data, to train personnel in its use, and to install some of the gauges well in advance of the test and the remainder sufficiently in advance to permit calibration of all systems prior to shot day. Construction of test buildings at an overseas location with the care necessary to avoid adversely affecting test behavior was a responsibility of the Santa Fe Operations Office of the Atomic Energy Commission (AEC) with the technical assistance of representatives of the Project Officers. Actual construction was successfully accomplished by Holmes and Narver under contract to the AEC.

The test was generally successful. Some of the structures were damaged so greatly that the amount of information was reduced and some had considerably less damage than was desired, but on the whole useful information was obtained. The success of the transient measurements was notable, particularly in view of the large number of difficulties involved. Analyses made subsequent to the test have in-

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dicated good agreement between the me[redacted] response and the response predicted on[redacted] basis of the measured loading. Also, methods of analyzing response have been improved as a result of test information. The situation is less satisfactory in regard to blast loading. Within a radius of about 3600 ft in Greenhouse Easy shot, the wave form was unusual in that the rise time was greater than that which would be found in a shock wave. There was a double peak, and the peak pressures were much lower than predicted. At greater ranges conventional wave forms were experienced, and pressures were closer to those predicted. Also the diffracted pressures on the back walls of structures were higher than expected from shock-tube studies at all ranges. The data from Program 3 have formed the basis for further experimentation and analysis. Methods of prediction are being steadily improved. The ultimate need is for relatively simple methods which can be applied with a reasonable degree of accuracy. The more tedious methods have been generally proved, and the day is not far off when quick methods [redacted]vailable to accomplish solutions of the [redacted] problems of predicting structural damage. Regardless of what may be done theoretically, however, it will always be necessary to use judgment to avoid pitfalls resulting from construction variations which may affect the generalized method.

In addition to the preceding information, a large amount of data that have direct usefulness was gathered. The value of earth cover in reducing damage to underground or partly buried structures was emphasized. The great resistance of shear walls in resisting blast damage to buildings was demonstrated. The necessary data for modifications of standardized military structures to provide greater blast resistance were obtained. The mode of failure of buildings furnished a better understanding of structural damage. The benefit of having windows open to reduce hazard from flying glass and the utility of $\frac{1}{4}$-in. mesh hardware cloth well attached to the inside of a window frame to stop the larger and more lethal glass fragments were tentative results.

Chapter 2

Program 4, Cloud Physics

2.1 GENERAL

In Program 4 much of the data is still in the reduction process at the present time; however, the trends are now obvious.

It is interesting to note the success of the aerograph systems designed by the Kollsman Instrument Corp. which are now being used in Air Weather Service aerial reconnaissance planes as a result of success in Greenhouse.

The most significant results of the program became known by accident in Project 4.6. Although the results are by no means conclusive, they do indicate that a considerably larger percentage of activity is carried on particles of nonfilterable size than was suspected up to the present time. This points out a difficulty in filtering air for pressurized crew quarters in aircraft required to operate in the vicinity of atomic clouds and is of considerable tactical significance.

The next most significant result is that some order of magnitude has been set upon the velocity and duration of the afterwind. It appears that this wind has been greatly overemphasized.

In the project for determination of the water content of the cloud, it has been demonstrated that seeding of an atomic cloud is not feasible.

Probably the most far-reaching result is in the research of C. Palmer in methods of forecasting tropical weather systems and in establishing trajectories for the dispersion of the atomic bomb cloud.

As a whole the program was successful in answering a number of questions vital to the military establishment which could have been answered in no other way.

2.2 PROJECT 4.1

The purpose of this project was twofold. First, it was desired to suitably document the cloud during its rise to obtain information of use in tactical airdrops and also to permit studies to be made of the physics of the cloud as to entrainment of air, turbulence, diffusion, and other pertinent factors. The second objective was to determine the physical characteristics of the cloud, such as water-vapor content, temperature, etc., which would contribute information as to whether such a cloud could be seeded to produce artificially stimulated precipitation of rainfall with subsequent scavenging of radioactive material from the cloud. This latter study was to be performed without actually performing a seeding operation.

The first objective of documentation was carried out from the air and the ground.

On the whole the documentation cameras were successful in obtaining useful data on all shots. The ground cameras failed to obtain a record on Dog shot owing to the low overcast which obscured the rising cloud, but adequate coverage was obtained from the air. Ground and air coverage was obtained on both Easy and George shots with excellent results. Analysis of data taken by the observers using theodolites on George shot showed that the cloud attained an altitude of 26,200 ft in 1 min and 45 sec, an altitude of 45,000 ft in 3 min and 33 sec, and a final altitude of 62,000 ft in 11 min and 4 sec. The radius of the cloud at 26,200 ft was 1.2 miles; at 56,500 ft, 3.2 miles; and at 62,000 ft, 5.1 miles. It is interesting to note that the pattern still persists, which seems to indicate that an atomic bomb cloud requires from 11 to 12 min to reach maximum altitude regardless of yield. It is also interesting to note that the George shot cloud was the first to actually penetrate the tropopause.

It can be concluded that it is possible to obtain measurements on an atomic cloud by means of trained observers with theodolites or nepho-

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clinometers, but the increase in accuracy and detail of the measurements when photographs are also available is very great. If cloud observations are to be undertaken in future tests in the Marshall Islands, the probability of success might be increased by making the tests earlier in the year. The short climatological record which is available for Eniwetok suggests that the cloudiness starts to increase markedly in May and June. Another way of increasing the probability of getting good cloud coverage under Eniwetok weather conditions is the establishment of a number of widely separated sites in order to increase the chances of catching a glimpse between the cumulus clouds.

In order to study the second objective the Kollsman Instrument Corp. developed a new aerograph at the request of this project which was capable of operation in a drone aircraft on a fully automatic basis. A total of 30 aerograph flights were made in and around atomic clouds arising from the three shots.

Analysis of a portion of the flights reveals no striking temperature or humidity features in an atomic cloud as compared to an ordinary cloud. The temperatures as indicated by the aerograph were lower inside the atomic cloud than in the environment. This apparent anomaly is being investigated further to determine whether it is real. Comparison of the indicated air speed to the time of entrance into the cloud revealed that in the majority of the traverses a sudden increase in the air speed was experienced although the power, controls, surfaces, etc., remained at constant settings.

The humidity traces revealed rather low humidities in the atomic cloud. These values grouped around 40 to 60 per cent relative humidity. This is evidence that the portion of the atomic cloud traversed does not contain liquid water in sufficient amount to entertain any speculation about creating rain by artificial seeding.

2.3 PROJECT 4.2

This project was designed to measure the wind produced by the inrush of surface air which pours into the rising column of hot gases produced by the rising fireball. The magnitude of such a draft wind in the area surrounding the blast had never before been measured, and whether this wind was significant enough in velocity and duration to produce structural damage, and also the possibility that the wind might be significant in pulling surface soils and other materials into the rising column of the cloud, was the subject of considerable speculation.

Twenty-five Pitot type wind-measuring instruments of standard design were modified for this type of measurement and were, on the whole, partially successful in obtaining "order of magnitude" results. One new and untested anemometer of the hot-wire type and another of the strain-gauge type were also tested for suitability in this type of service.

Results of Dog shot were unsuccessful in obtaining useful afterwind data owing to the paralysis of the recording devices by the negative or suction phase of the blast which obscured a majority of the afterwind records obtained. The results of this test, however, led to suitable modifications of the instruments, which resulted in a new design that tended to equalize the effect of the negative phase of the blast wave.

On Easy shot the magnitude of the surface component of the afterwind was found to be considerably less than anticipated and measured from 26 to 32 mph (including the normal surface-wind component) at distances from 1200 to 2488 yd. The duration of the afterwind was found to be approximately 15 sec after passage of the shock wave at this location. This would seem to indicate that a large quantity of air which rushes in behind the fireball probably is drawn from the immediate vicinity of the fireball and that a chimney action is not sustained for any appreciable length of time from ground level.

On George shot three instruments yielded records at 1260, 4750, and 7870 yd, respectively. Although the Pitot tube was destroyed on the recorder at 1260 yd, the direction record indicated that for this larger shot the afterwind phase lasted 5 min at this position. The afterwind effects at the greater distances, indicated largely by alteration of wind direction, lasted only 12 and 7 sec, respectively, with minor changes of wind speed of 2 to 6 mph.

It would appear, from the meager results of this test, that any large afterwinds which might result from the rising fireball must be confined to a radius of approximately 1200 yd for weapons of the present tactical size. Since this is within the range of total blast destruction, the only practical application of afterwinds would be their role in drawing ground debris into the rising cloud column. With extremely large

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weapon yields the afterwind may play a significant part in surface destruction, although this appears unlikely.

2.4 PROJECT 4.5

This project is part of a long-range program in tropical weather forecasting and is considered to be a part of the Greenhouse program only because of the unprecedented number of weather observations which were available during the test period. This work is under the direction of C. Palmer of the University of California at Los Angeles (UCLA), who is the foremost authority in tropical forecasting in the world.

It is too early to determine the results of the study of the meteorological data which were obtained during Operation Greenhouse; however, it can be mentioned that an entirely new method of forecasting using upper-wind trajectories was tested and found to be quite encouraging. It should be pointed out that the usual forecasting techniques employed in temperate latitudes involving the interpretations of highs and lows in barometric pressure are entirely inadequate in the tropics owing to the different nature of the circulation in the tropical latitudes. The field of tropical forecasting is almost a virgin one and will involve the formulation of an entirely new concept.

It is believed that, with further refinements, the Palmer method of tropical forecasting will prove to be a tremendous step forward in the art of forecasting weather in the tropics. It is recommended that this method be used as an adjunct to present methods in any future test programs in the Marshall Islands.

2.5 PROJECT 4.6

This project was initiated to study the ionic structure of the cloud from the standpoint of atmospheric conductivity. A total of four aircraft were equipped with suitable equipment for the measurement of conductivity. Two of these were L-13 liaison aircraft which were equipped with one small ion-conductivity chamber for low-altitude crater and local fall-out surveys. The remaining two were long-range B-50A aircraft designed for tracking the cloud up to three days after shot time and were fitted up as flying laboratories. These aircraft were equipped with instruments to measure both positive and negative small-ion density and large-ion density simultaneously with continuous records of atmospheric nuclei counts, electrostatic field, humidity, pressure, temperature, air speed, filter-paper samples of the atmosphere, actual gaseous samples of atmosphere compressed into high-pressure containers, and gamma counting rates using a scintillation counter.

The plan of operation was to intercept the atomic cloud 4 hr after shot time with the B-50A aircraft and run contours around the outer edge continuously to obtain the size and rate of growth of the cloud and at the same time to determine the density of large and small ions on the fringes of the cloud. This was done from 4 to 72 hr after the blast.

General contours of conductivity around the cloud showed it to be about 300 to 400 miles long by 50 to 150 miles wide at 6 hr after the shot and 600 to 1000 miles long by 100 to 200 miles wide at 30 hr after the shot. The preceding information was obtained at 25,000 ft for the wind patterns which existed at the times of Dog and Easy shots. The existing wind patterns indicated that vertical mixing occurred between the 20,000- and 35,000-ft altitudes. The position and size of the cloud could not be explained otherwise, since the cloud was several times longer and farther away than predicted by the 25,000-ft wind patterns alone or by fall-out since the size of the particles measured was believed to be extremely small.

One rather unexpected result of the tests was an indication that a surprisingly large portion of the radioactivity might have been carried on submicron particles which were too small to be filtered out by the normal filter methods. This was first suspected when the activity collected on the filter papers failed to account for the actual ionization measured by a factor of greater than 50. So far it cannot be positively stated that these submicron particles are the major contributors to the activity of the cloud as compared to the 4- to 10-μ particles collected by the filter papers, but it is very difficult to interpret the evidence collected to date in any other manner.

The L-13 aircraft made flights at elevations ranging from 200 to 4000 ft in altitude. It was found that at an altitude of 200 ft the contamination contours on the shot island and adjacent islands could be rapidly obtained from the air, which agreed very favorably with the ground contours taken by the radiological safety (Rad-Safe) monitors. At higher altitudes the entire atoll was examined from the air, and the pattern of fall-out from the cloud was easily observable.

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Chapter 3

Program 5, Radiological Instruments

3.1 PURPOSE

The test of radiological instruments conducted as Program 5 of Operation Greenhouse consisted of two projects: (1) the evaluation of ground radiac equipment and (2) the evaluation of air-borne radiac equipment. "Radiac" is a coined word which has been adopted by the Department of Defense (DOD) meaning "radioactivity detection, identification, and computation." This equipment, which was developed expressly for military, civil defense, and AEC applications, was tested at Eniwetok under field conditions where the radiations from controlled atomic explosions were present. Operation Greenhouse offered the first opportunity since Operation Sandstone in 1948 to field-test new radiac equipment in a thorough manner.

3.2 PROCEDURE

3.2.1 Evaluation of Ground Radiac Equipment

The ground equipment selected for evaluation under actual field conditions consisted of 21 types of dosimeters, 16 types of survey instruments, a radiological field laboratory, and four laundry-monitoring devices, all of which were developed after Operation Sandstone. These types included equipment developed by, or under the sponsorship of, the Army Signal Corps, the Army Chemical Corps, the AEC, and the Bureau of Ships of the Navy.

The dosimeters were exposed in ventilated aluminum hemispheres, approximately 18 in. in diameter, as shields against damage from blast, dust, and temperature effects. The hemispheres were placed at locations chosen on the basis of an estimated total gamma dosage of 3000, 1000, 500, 200, 100, 50, 25, and 5 r. Other dosimeters to be evaluated were placed in Army tanks at various locations from Ground Zero and in drone aircraft participating in sampling operations. Some low-range dosimeters were carried into the contaminated zone by the Rad-Safe monitors who entered the blast area after detonations. Portable survey instruments, including ionization chambers, Geiger-Mueller (G-M) counters, proportional counters, and scintillation counters, were taken into contaminated areas by survey teams at the earliest possible moment after detonation. The radiological field laboratory consisted of a lightweight trailer with equipment for analyzing water, air, and ground samples; for checking alpha, beta, and gamma contamination; and for measuring decay rates. The laboratory was designed to determine the necessary information for an estimate of the hazard in occupying a contaminated area and also to provide analytical information for other projects. Various laundry-monitoring systems which had been developed for use by the Quartermaster Corps were tested under field conditions.

3.2.2 Evaluation of Air-borne Radiac Equipment

The air-borne radiac equipment evaluated was developed in anticipation of two operational problems likely to be encountered by military aircraft in an atomic war. It was felt that more than one bomb might be dropped in a given area, causing an intense and sustained radiation throughout a large region of the atmosphere. In such an eventuality it would be essential that this air mass be delineated and closely followed to ensure that it would be avoided by friendly aircraft and that personnel could be evacuated from possible fall-out areas. Further, it was

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realized that an airplane might have to enter such a cloud, and it was therefore necessary to provide a means whereby the pilot could estimate the intensity of radiation in his aircraft, as well as his cumulative dose, at any instant. These problems were met by developing the following equipment:

1. A cloud tracker, AN/ADR-3 and type D-1, to detect the radioactive cloud at ranges up to 20 miles.
2. A gamma-intensity meter, AN/ADR-1, to indicate the intensity of radiation in the airplane.
3. A dosimeter, AN/ADR-2 and type B-1, to indicate both the instantaneous and total doses received by the air crew.
4. A cabin monitor, type E-1, to indicate an inhalation hazard to crew personnel due to a dangerous concentration of radioactive material in the air in the interior of the plane.

Ground contamination with radioactive materials can be effected either by an atomic explosion or by dusting with by-products from an atomic pile. In a beachhead landing from the sea, in parachute invasions, or in the reoccupation of airfields or other installations, it would be essential to survey the landing area to ensure that it did not constitute a radiation hazard. Such a survey could most rapidly be conducted from the air. The Navy Bureau of Aeronautics and the Air Materiel Command (AMC) met the problem by developing the following equipment:

1. A ground-survey device, AN/ADR-4 and type F-1, which measured the radiation emitted from radioactive ground sources as the airplane flew overhead. The indications of this device were continuously correlated with strip photography of the area and a device which automatically plotted the course of the airplane on a suitable grid.
2. Droppable gamma-intensity telemetering units, AN/USQ-1, which were dropped in a suitable pattern into the contaminated area. Signals from these units were received on a recorder, AN/ARR-29, aboard the aircraft overhead.

For the purposes of the tests, an Air Force B-17 and a Navy P2V-2 were identically instrumented. This duplication was considered desirable to ensure that at least one airplane was in operation in the event one was grounded and to permit either airplane to assume the additional responsibilities of the other. In general, however, the B-17 was to track the atomic cloud while the P2V-2 attended to ground survey of the explosions and to tests of telemetering units.

3.3 RESULTS

3.3.1 Evaluation of Ground Radiac Equipment

(a) Dosimeters. No dosimeter was found to be entirely adequate within the scope of field usage and the military characteristics. Although some instrument types were consistent in themselves, little intercorrelation was observed. The problems of calibration, sensitivity, accuracy, energy dependence, rate dependence, leakage, decomposition, photosensitivity, reliability, and ruggedness still have not been completely solved. Dosimeters which reacted favorably in some respects failed in others. However, some dosimeter types are more adequate than others, and most types can be made adequate with varying degrees of further development.

There is a common dose range of interest to the DOD, the AEC, and the Federal Civil Defense Administration, namely, 0 to 600 r. The instruments tested during Greenhouse cover this range, but some instrument types are more suitable for specific portions of this range than others. For a range up to 50 r, self-reading pocket electroscopes are most feasible because of their inherent accuracy and continuity of readings. However, pocket chambers are also feasible if requirements exist for devices which are not self-reading. For higher dose ranges, from the biological threshold of approximately 50 to 600 r (approximately 200 r higher than the median lethal dose), solid-state and liquid-state devices are more feasible than gas-interaction types (chambers and electroscopes). The former dosimeter types are more effective in this range since neither the accuracy nor the continuity of reading of gas-interaction types is required when viewed from the tactical and medical segregation viewpoints.

(b) Survey Meters. On the whole the AN/PDR-T1B was the most reliable survey instrument tested during Greenhouse. The AN/PDR-T1A and the AN/PDR-T1B are sufficiently reliable to serve as interim military ground-area surveying instruments despite several bothersome characteristics, e.g., drift, sensitivity to shock, and grid current. The AN/PDR-T1B is as good as, or better than, the AN/PDR-T1A in every respect but one, viz., the readability of the meter. The AN/PDR-34 is the only standard military instrument capable of high-intensity beta detection, and thus it must be retained. Further development work was recommended

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on the AN/PDR-23 (XE-1) and the AN/PDR-23 (XE-2) survey instruments. The AN/PDR-27A is the best of the standard military probe type instruments currently available. However, its design renders it inadequate for ground-area monitoring because of insufficient range in the high-intensity region.

The AEC SGM-4E was very reliable and rugged and was particularly useful in checking low-level contamination. The AEC SDX-4A was very useful for any condition requiring extreme gamma sensitivity such as remote surveys and low-level contamination monitoring.

(c) Radiological Field Laboratory. Operation of the mobile radiological field laboratory threw light on a number of important factors. The original design and procedures were too sweeping in scope to allow for efficient field operation, and it was seen that the laboratory should have been designed and equipped to meet a few specific needs. On the basis of these findings, from tests performed on the precursor to the present model of field laboratory, certain modifications were found to be desirable. These modifications limited the scope of the field laboratory but stressed the procedures which yielded the maximum of useful information and so increased the efficiency of the operation.

(d) Laundry-monitoring Systems. No field laundry-monitoring system was found to operate satisfactorily in the tests. A monitor using a flow-counter detector is unsuited for field use. The mechanisms necessary in the roller principle present a potential maintenance problem in the field. The suitcase principle is also unsuited for a field decontamination laundry. The table-top principle conforms to military field needs and could serve as a guide to future development.

3.3.2 Evaluation of Air-borne Radiac Equipment

The tests of air-borne radiac equipment demonstrated very clearly the shortcomings as well as the advantages of the various equipment and techniques used.

(a) AN/ADR-1. This radio equipment worked very satisfactorily during this operation. The test results indicate that this equipment would make a very good interim air-borne radiac instrument until such time as a lighter and smaller unit is developed. This unit should also have a top range of 500 r/hr.

(b) AN/ADR-2. Although this equipment worked satisfactorily throughout the entire test, it appears that for general use the functions that the AN/ADR-2 was originally called upon to perform can be obtained more expeditiously by other instruments. The dose-rate vs time information can be obtained better on the AN/ADR-1, and the accumulated-dosage information can be obtained by an extremely small, lightweight, and simple instrument employing some of the circuitry developed in the AN/ADR-2.

(c) Type E-1 Beta Air Monitor. This monitor was built to evaluate the detection technique employed and was not designed to withstand the extremes of environmental conditions encountered at Eniwetok. A great deal of difficulty was encountered in maintaining the electronic circuitry in an operating condition; however, good results were obtained in one drone installation, and it is felt that these results show that this detection technique is satisfactory for the selective detection of beta particles in a high gamma field.

(d) AN/USQ-1 and AN/ARR-29 Telemetering System. Approximately 40 per cent of the AN/USQ-1 telemetering units operated satisfactorily. The outstanding deficiencies in the equipment were the mechanical accessories. The electronics, as far as could be determined, worked very satisfactorily. The mechanical devices which gave practically all the trouble included the mechanical timer, which energized the equipment after a preset delay time, and the antenna-erection mechanism. Improvements recommended for these units include work on the mechanical accessories and an extension of the radio telemetering range.

(e) AN/ADR-4. With a few minor improvements, this instrument will make very effective operational air-borne ground-surface-survey equipment. This equipment will be a valuable asset to air-supported ground atomic warfare.

(f) Type F-1 Ground-survey Equipment. Although this equipment suffered from extreme instability during the test, it was apparent that the detection head had some directivity; it was also apparent that the directivity was no better

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than the directivity obtained by the use of shadow shielding employed in the AN/ADR-4.

(g) AN/ADR-3. Although this cloud tracker operated satisfactorily during two of the three shots, it fell short of expectations. The most salient difficulty was the reception and detection of spurious and unaccounted for signals. Additional research and development work to increase the sensitivity and speed of response of the equipment was recommended.

(h) Type D-1 Cloud Tracker. Operation Greenhouse tests indicate that the type D-1 radioactive cloud detector and tracker will satisfactorily determine and indicate the direction of the radioactive cloud, and that it should be usable as an interim short-range instrument, provided the high-voltage power supplies are modified to enable them to withstand high humidity and salt-spray conditions.

(i) Mark 7 Infrared Equipment. Although this equipment detected the radioactive cloud, it also detected ordinary clouds. Further, any detection system employing radiation in the infrared portion of the spectrum is extremely dependent upon weather and atmospheric conditions. If an ordinary cloud or overcast area lies between the radioactive cloud and the detecting equipment, the atomic cloud will not be detected. Rain will very greatly reduce, or even completely eliminate, the signal received by the detector from the radioactive cloud. Because of these extremely limiting operating conditions this technique does not appear to be practical.

3.4 CONCLUSIONS AND RECOMMENDATIONS

Conclusions were reached and recommendations were made with regard to the adequacy of the equipment, adequacy and feasibility of existing military characteristics, direction of future developments, and the necessity for future tests and improved test methods. Details of these conclusions and recommendations can be found in the technical reports covering Projects 5.1 and 5.2

In general, as a result of these experiments, the operating agencies of the military and civil defense organizations can use the data obtained in selecting, from existing radiac instruments, the instruments which are best suited to their particular needs. These data will aid in understanding the capabilities and limitations of those instruments which are selected. The evaluation of radiac equipment will assist development agencies of the various organizations concerned in guiding further development of radiac equipment.

During Operation Greenhouse, 16 distinct types of survey meters were tested. Some of the equipment was relatively new, but a major portion had been designed and in use for periods up to several years. Greenhouse testing, therefore, "caught up the slack," and it is not anticipated that during the intervals between future tests such a variety of untested equipment will be available. Of the Greenhouse instruments, it was recommended that only two, the AN/PDR-23 (XE-1) and the AN/PDR-23 (XE-2), be subject to additional tests and that they be included only if development has indicated substantial improvements.

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Chapter 4

Program 6, Physical Tests and Measurements

4.1 GENERAL

The Physical Tests and Measurements Program consisted of ten projects:

6.1 Cloud-particle Size and Distribution
6.2 Thermal Effect on Materials
6.3 Exposure of Combat Vehicles
6.4 Fall-out Distribution
6.5 Survey-meter Interpretation
6.6 Filter-material Evaluation
6.7 Contamination and Decontamination Studies Aloft
6.8 Cloud Radiation Field
6.9 Protective Clothing
6.10 Collective-protector-equipment Evaluation

The objective of the over-all program was to determine many of the physical effects and characteristics of an atomic bomb detonation not previously understood or recorded. This information was needed for future defensive planning as well as for further research through laboratories within the United States.

4.2 PROJECT 6.1, CLOUD-PARTICLE SIZE AND DISTRIBUTION

4.2.1 Purpose

The objective of this project was to obtain basic data on the gaseous and particulate fractions of atomic clouds collected close in during the test detonations. These data included the gross radiochemical composition and concentration of particulate radioactivity, analysis for certain gaseous activities, gross and radioactive particle-size distributions, and gross decay rates of radioisotopes contained in particulate matter.

The information was desired to assist in the designs of air-borne protective equipment; to guide the development of simulated contaminants for laboratory experiments; to predict severity and extent of the fall-out; to predict the area of contamination and its relation with well-defined conditions of detonation; to prove whether previous methods of particle collection were correct and adequate; and to provide a means, through decay of particulate samples, for predicting the disintegration rate of atomic clouds.

4.2.2 Procedure

The drone aircraft used in this project were equipped with four instruments: an electrostatic precipitator, a cascade impactor, a snap sampler, and a centrifugal conifuge for collecting cloud samples of the cloud shortly after detonation. Every effort was made to achieve isokinetic sampling conditions by all instruments to ensure that representative particle-size samples were obtained for laboratory analysis. The analysis of these samples was conducted at two government laboratories, the United States Naval Radiological Defense Laboratory (USNRDL) and the Chemical Corps Chemical and Radiological Laboratories, and at the Berkeley and Boston laboratories of Tracerlab, Inc., as contractor to the government.

The drone aircraft, in general, made two passes through the cloud at approximately 3 and 8 min after detonation, during which period the cloud was still rising. The cloud was sampled at eight altitudes ranging from 16,000 to 30,000 ft true altitudes in 2000-ft intervals. The sampling altitudes were dictated by the positioning of the drone aircraft for Project 1.7. In general, these altitudes suited the purposes of

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Project 6.1 in that they were chosen to obtain adequate samples prior to dispersion of the cloud.

4.2.3 Results

All sampling apparatus operated satisfactorily, and adequate samples were collected by all apparatus except the conifuge. The lack of an adequate sample in the conifuge was due to a combination of the low sampling rate and the short time drone aircraft were in the cloud. Information obtained on the use of the instrument will permit improvement in its application for future tests.

By analysis of the samples from the other apparatus, useful data were obtained on total particle-size distribution, radioactive particle-size distribution, ratio of active to inactive particles, fractionation of radioactivity with particle size, specific activity of particles in various size ranges, decay rate of particulate radioactivity in total and size-graded samples, estimates of the activity per unit volume of the cloud, relations of beta activity with kiloton equivalent of the shot, radiochemical composition, energy, and beta-gamma ratio of particulate matter, density of particles, and production of neutron-induced activities in particulates. Summaries of these data obtained are contained in Technical Report, Annex 6.1, WT-72, Cloud Phenomena: Study of Particulate and Gaseous Matter.

4.2.4 Conclusions

Further study of the data obtained in this project is necessary to apply the knowledge gained to problems of (1) evaluation of personnel equipment and (2) contamination-decontamination studies of equipment and material.

Also, a project is required at a future atomic-weapons test of the normal airdrop type to make sufficient measurements relating to the cloud to permit a correlation and extrapolation to air-burst conditions of the information developed by this project. The existence of a tower, which contributes a large portion of the particulate mass, and the low-altitude detonation of 300 ft, which results in the upsweep of coral around the base of the tower, influence the results obtained in this project to an unknown degree.

Laboratory studies related to determining the association of activity with particle size need to be extended to improve the data from future tests and to determine the relative amount of activity associated with each size fraction. These data are necessary to establish limits for particle size of primary interest in hazard evaluation and contamination-decontamination studies.

Future instrumentation should be directed to assess the relative percentage of the total activity associated with each particular size fraction. This would permit an assessment of the data to determine the size ranges that are of specific interest in hazard evaluation and contamination studies.

4.3 PROJECT 6.2, EFFECT OF THERMAL RADIATION ON MATERIAL

4.3.1 Purpose

The study of thermal-radiation effects on material was intended to determine actual conditions under an atomic bomb detonation which could be translated into subsequent laboratory testing. The objective of this experiment was to obtain data for:

1. Comparison of a field source to laboratory sources using detectors or materials sensitive to different wavelengths of thermal radiation.
2. Comparison of field-exposed materials with laboratory-exposed materials, emphasizing the selection of comparison standards with widely variant characteristics for the absorption and reflection of radiant thermal energy.
3. Determination of the influence of the environmental situation on material damage to permit extrapolation from results obtained at Eniwetok to other geographical regions.
4. Correlation between effects of small and extended radiant beams on material samples to obtain laboratory scaling factors.
5. Temporal observations of the development and propagation of fire and flame under field conditions.
6. Analytical studies by the Army Ordnance Department of the effects of geometry on fire initiation in order to aid in more effective planning of field and laboratory tests.
7. Check of the predictions of the combustibility of common structure materials with a small number of samples.

4.3.2 Procedure

The thermal-radiation characteristics of greatest interest were the total energy, the time-intensity relation, and the spectral dis-

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tribution. Measurements of these characteristics were made using calorimeters with oscillographic recorders, rotating drums with sensitive-paper indicators, and passive receivers consisting of metal foils. Those materials used in the incendiary program were chosen for studies of the effects of such factors as area, backing material, geometry, and reflectance on the incendiary characteristics. A number of the materials used in the field were previously exposed to laboratory sources. Documentation was carried out by means of motion pictures.

4.3.3 Results

The total thermal-energy values at approximately 2 miles from Ground Zero were found to be about one-half those expected. The values at the closer stations were found to be even smaller fractions of expected values. Time-intensity curves indicate that this further reduction is due to obscuring material arising at about 0.5 sec between Ground Zero and the points at which measurements were made. Peak intensities were reached in approximately 0.25 sec, and it is probable that most thermal damage occurred within 1 sec. Since the shape of the thermal pulse was different for each station, it was necessary to make time corrections in the analysis of the passive-receiver data.

Rough spectral measurements indicated that the bulk of the thermal radiation was in the visible portion of the spectrum, although all measurements are uncertain to 10 per cent of the total thermal energy. With this uncertainty no ultraviolet energy was found, and the infrared energy beyond 1 μ was measured to be only 10 per cent. On the basis of these results all existing laboratory sources would appear to overemphasize the infrared portion of the spectrum.

A large amount of data was obtained concerning the effect of the field radiation on materials previously exposed to laboratory sources, thereby offering a means of comparing the actual and simulated sources.

The incendiary experiments showed that small individual samples of solid combustible materials such as wood and cloth did not sustain fires for more than 1 sec or so. For the stations used, no fires existed at the time of arrival of the blast wave. However, indications are that the proper combination of materials arranged in suitable geometry may result in sustaining primary fires.

4.3.4 Conclusions

The measurement of total energy at the locations where material effects were measured, as well as a rough spectral breakdown of this energy, using calorimeters, rotating drums, and passive receivers was moderately successful. Uncertain measurements with the calorimeters led to incomplete results. Elimination of mechanical difficulties and increased familiarity with the limitations of the instruments should provide more reliable measurements in future tests. For accurate calorimeter measurements in the future, four series of calibrations appear advisable: careful laboratory calibration of all components before leaving for the field, field calibration before and after experimental use, and another laboratory calibration on return of the equipment from the field.

The development of more sensitive indicating materials, the more accurate spacing of indicating strips, the more accurate measurement of color changes, and an increase in the number of slits and the rotation speed of the drums would all tend to improve results in the future with the rotating drums.

Measurement of total energy using the passive receivers depends upon a knowledge of the time of exposure. If the shape of the field time-intensity curve could be established, and if the indicators could be calibrated with thermal pulses duplicating this field shape, it would appear that accurate results could be obtained. The reproducibility of results obtained with the passive receivers indicates that less duplication is required. The same number of foils would provide more useful data if increased resolution were attempted by a decrease in the thickness interval between successive foils.

The nature of the results obtained, particularly the effect of obscuring material, indicates the need for additional information from future atomic bomb field tests. In particular, it is considered desirable to obtain information from several sizes of detonations and for air bursts.

4.4 PROJECT 6.3, COMBAT-VEHICLE EXPOSURE

4.4.1 Purpose

The objective of this project was to determine the over-all combat effectiveness of the medium tank and crew under conditions of atomic bomb

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attack. The data so compiled were to be used in developing a tactical doctrine for employing armored vehicles in both offensive and defensive situations. Particular emphasis was placed on measuring the effects of ionizing radiation, blast pressures, and accelerations in the fighting compartment.

4.4.2 Procedure

Although the value of using several types of heavy ordnance equipment was recognized, the physical size and difficulty of transporting this equipment imposed a limitation on the number which could be used. Accordingly, only ten medium tanks (eight M-26 and two M-46) were exposed during this project. These vehicles were located at ranges of 500, 750, 1000, 1233, and 1400 yd from Ground Zero with various orientations relative to the burst point, i.e., head-on, side-on, or tail-on. In each case the tanks were completely buttoned up and hatches were locked. The guns were in travel position, with the main armament, the 90-mm gun, in the reversed position. The tanks with a side-on orientation had the barrel locked in place in the traveling yoke. All other guns were not locked and were at 0° elevation.

The tanks were instrumented to obtain such information as the total ionizing radiation at various points of the interior, the wall temperature of the interior as a function of time, the heating of the interior, the rise of interior pressure caused by the passage of the blast wave, and normal and cross acceleration. Neutron-intensity measurements were made utilizing sulfur buttons and gold foil. Gamma-intensity measurements were made using film badges and phosphor-glass dosimeters. Accelerations were measured by differential-inductor and self-recording accelerometers; the pressure changes inside the tank due to the passage of the blast wave were measured by differential-inductor type gauges using a twisted Bourdon tube. Whenever feasible, a primary means of measurement was "backed up" by a secondary means of less cost and accuracy. This was done to compensate for the rather low reliability of operation of the instruments used.

4.4.3 Results

In considering the effect of atomic blasts on crew personnel of armored vehicles, it was found that lethal dosages of radiation were obtained to distances of 900 yd; median lethal dosages, to 1000 yd; serious radiation sickness, to 1200 yd; and moderate radiation sickness, to 1400 yd. The acceleration imparted to the vehicles would have caused serious to fatal injuries at distances from zero point to 900 yd but was insignificant at distances of 1100 yd and beyond. Interior temperature and air pressure would not have had any serious effect on crews although a marked rise in temperature and pressure was noted up to 1000 yd. The majority of the damage to the vehicles was limited to external accessories and appendages. The small amount of major damage suffered resulted from the overturning of two vehicles and the loss of a turret from another.

4.4.4 Conclusions

The results of the project indicate that the effects on crew members are much more serious than those on the vehicle itself. Within those vehicles rendered unfit for combat by violent displacements, complete crew casualty is immediate. At greater ranges from Ground Zero, lethal radiation dosages are incurred by the crew, whereas the medium tank suffers no loss of combat effectiveness. The effects of blast pressures within the crew compartment are of little consequence. In general, the combat effectiveness of the vehicle and crew may be given as follows:

1. Combat effectiveness of vehicle alone: 0 per cent, 0 to 500 yd; 0 to 100 per cent, 500 to 1000 yd; 100 per cent at distances over 1000 yd.
2. Immediate combat effectiveness of crew: 0 per cent, 0 to 900 yd; 0 to 100 per cent, 900 to 1100 yd; 100 per cent at distances beyond 1100 yd.
3. Delayed combat effectiveness of crew (periods greater than 24 hr): 0 per cent, 0 to 1200 yd; 0 to 100 per cent, 1200 to 1600 yd; 100 per cent at distances beyond 1600 yd.

The above conclusions apply specifically to existing conditions on Easy shot. Cognizance must be taken of this since many factors which could alter results were not representative of combat conditions. Among the more important variations from true field conditions are: (1) The vehicles carried no ammunition, whereas ammunition stored in ready racks could be dislodged and thereby injure the crew. (2) All vehicle hatches were closed and locked, whereas, in combat, hatches are closed but not locked. (3) The brakes were set and locked, and acceleration effects could be influenced greatly.

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(4) The gasoline tanks were full of either gasoline or water; the more normal condition of half-full gas tanks should be checked. (5) The vehicles were located either perpendicular to or aligned with the expected direction of the blast; preliminary indications that an oblique orientation would effect more serious damage should be checked.

It is believed that a careful study of the results gained from this project and from future tests, together with a study of the significant differences between tanks and other ordnance equipment, will result in a means of making adequate predictions of the effects of atomic weapons on all ordnance equipment.

The continuation of the test program should fall into two categories. First, the information concerning medium tanks should be completed. Second, tests on other ordnance equipment should be made. Also, the contaminability of, and effective decontamination procedures for, tanks should be studied. It appears that long-time adverse effects on personnel could be experienced from dust inside the vehicles, and the real extent of this potential hazard should be determined by collecting and counting dust samples.

4.5 PROJECT 6.4, FALL-OUT PHENOMENOLOGY

4.5.1 Purpose

The objective of this project was to collect samples of the primary and secondary fall-out from the Greenhouse atomic bomb detonations with the view of determining the level of activity, the pattern of the fall-out, and the chemical nature of the active fall-out particles. This information was required for predicting fall-out patterns and probably external and internal hazards to personnel from fall-out particles from other atomic bomb air bursts.

4.5.2 Procedure

To meet the requirements of the experiment and the physical conditions at the site, a fall-out collector was designed. This collector consisted of a 1-ft-square aluminum plate which is held in a horizontal position by a plate holder. The plate was covered with a thin layer of grease to trap the particles that fell on it. The plate was then placed in a boxlike frame and made watertight to prevent washing away of fall-out samples.

A few hours after the shots, each island was visited, and the activity of the plates was checked. Activity of the plates on adjacent islands was checked for six days for indications of secondary fall-out. All the active plates were returned to the USNRDL for analysis.

4.5.3 Results

The fall-out samples were divided by sedimentation procedures into three sizes. The results of this procedure indicate a moderate amount of radioactivity on particles in the small- and medium-size fractions from the Dog shot samples. These results differ consistently from the results of the Easy shot fall-out analysis, which indicate that practically all of the radioactivity is associated with the large fraction. Since the settling velocities of particles in air indicate that the fall-out should consist of large particles only, the apparent high percentage of active small particles in the Dog shot fall-out is surprising. However, during the process of separation of the small and medium fractions, the samples were suspended in water and subjected to ultrasoneration. At this point it is probable that an appreciable dispersion of the particles occurred. Very few radioactive particles smaller than 2 μ in diameter were found, and it appears that most of the radioactivity of the small fraction was due to the small radioactive spheres removed from the large coral grains during the sedimentation procedure.

Other data were compiled in this project concerning origin of the fall-out particles, mechanism of the fall-out, and influence of local winds on the fall-out.

4.5.4 Conclusions

The primary purpose of Project 6.4 was to provide data for determining the health hazard to personnel resulting from radioactive fall-out from low-level atomic bomb detonations. The fall-out during Operation Greenhouse was not heavy enough on any island except Bogallua to cause a serious danger from external radiation. It was computed that a person exposed on Bogallua for 24 hr from initial time of fall-out would have received a total body dose of 117 r of gamma radiation alone.

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The danger of internal radiation from fall-out lies in the body retaining inhaled or ingested radioactive particles. The retention in the lung is most pronounced for particles 1 μ in diameter. Although only a very small percentage of the particles were of this size, small quantities could have been inhaled or ingested by personnel.

To clear up ambiguities which have arisen as to how many of the small active particles fell out independently or adhered to larger particles, it is believed that, in future fall-out studies, aerosol-collecting instruments such as electrostatic or thermal precipitators should be used at ground levels with the precipitation of particles upon microscope cover glasses. In this way the autoradiographic technique may be used to identify and measure the active particles.

4.6 PROJECT 6.5, INTERPRETATION OF SURVEY-METER DATA

4.6.1 Purpose

Since survey instruments and personnel dosimeters present the only practical method of detecting beta and gamma radiations, it is important that the instruments used for this purpose measure dose rates correctly. The response of these instruments to such contamination is primarily dependent upon the characteristics of the radiation fields arising from dispersal fission products. The objectives of this project, therefore, were (1) to establish the important properties of the radiation fields arising from fission-product contamination, which are important to survey instruments, and (2) to investigate the response of survey instruments to these radiations and thus obtain information as to the adequacy of several such instruments in measuring beta and gamma dose rates in fission-contaminated areas.

4.6.2 Procedure

Fission-product activity was collected on aluminum plaques which were flown through the radioactive cloud following each of the four bursts. Beta-ray dose rates were determined with specially constructed beta-ray surface chambers previously calibrated with beta-ray isotopes. With the use of aluminum absorbers, beta-ray absorption curves were run and compared with similar absorption measurements obtained using known beta-ray isotopes. Gamma dose rates were obtained by shielding out the beta-ray contribution.

The response of various types of commercially available G-M counters and ion-chamber counters to fission-product beta-ray and gamma-ray fields was studied. Many of the instruments studied were used as monitoring instruments at the test site. The low activity obtained on the plaques did not allow response data to be taken on personnel dosimeters as planned because of the long exposure time involved. However, the response of these dosimeters to beta rays of various energies was investigated.

Gamma-ray energies were determined by half-value-layer absorption measurements by use of narrow-beam geometry. In addition to the laboratory measurements, field determinations of residual gamma-ray energy were made in the vicinity of Ground Zero following Dog and Easy shots. All readings were made with a group of energy-dependent chambers calibrated to X-ray energies over a range of values from 25 kev to 1.20 Mev. The laboratory and field measurements effected a comparison between the primary gamma-ray energies resulting from multiple scattering.

The mean maximum beta-ray energy of fission-product contamination was determined by a comparison of absorption curves run on the fission products to a standard set of absorption curves run on a series of beta emitters ranging in energy from 0.50 to 3.55 Mev.

4.6.3 Results

Changes in beta-ray energy were studied for the period from 44.6 to 215.7 hr after zero hour. It was found that the beta-ray absorption curve could be reproduced by a high-energy and a low-energy component of beta radiations. For early times the two components were 1.54 and 0.5 Mev, respectively, and approached a relatively constant value of about 1.41 and 0.5 Mev after four days. The ratio of beta dose to gamma dose on the surface of the plaques was measured for Dog and Item shots and was found to be 157 and 156, respectively.

Laboratory determination of effective gamma-ray energies using half-value-layer measurements by means of aluminum, copper, and lead filters showed the energy to be dependent upon the absorber used. The energies measured were 0.5, 0.47, and 0.62 Mev for the respective absorbers. Field determination of gamma-ray energy in the residual fission-product field showed

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the energy to be between 83 and 127 kev. The gamma-ray energies measured under laboratory conditions at the test site showed no significant change with time between 8 hr and 10 days.

All survey-instrument readings were in good agreement with their predicted response to the measured radiation fields. Some predictions were made concerning personnel dosimeter response to radiation fields arising from fission-product contamination.

4.6.4 Conclusions

The data concerning the important properties of beta- and gamma-radiation fields indicate that for the conditions investigated the primary gamma radiation possessing an initial energy of approximately 550 kev is degraded through a process of multiple scattering to energies between 83 and 127 kev. The energy of scattered radiation, in this instance, was measured over a barren, level area of land at distances of 630 and 100 yd from Ground Zero. In other situations where terrain is more complicated, it is conceivable that gamma-ray energies would be different. In general, under conditions of widespread contamination, a large component of scatter radiation would exist.

The experimental data and the results obtained after the bursts, showing the calculated change of beta- and gamma-ray energy with time, are in general agreement. On the basis of the information obtained from the test, effective gamma-ray energy would be expected to change very little with time up to 100 days.

Because gamma-ray energies of the fission-product activity under laboratory conditions were different from those under field conditions, the laboratory study of the response of G-M and ionization-chamber types of survey instruments to gamma-ray fission-product activity does not depict the response of these instruments under field use.

The gamma-ray fission-product source used in the laboratory had an energy of approximately 550 kev. The response of the survey-meter instruments to fission-product samples and radium used for calibration purposes was similar. For gamma-ray energies of 83 to 127 kev, G-M type survey instruments will exhibit considerable energy dependence and will no longer be reliable gamma-ray-detecting instruments. However, the ionization-chamber type instrument with properly designed chambers will measure gamma-ray dose rates accurately within this energy range.

Present survey instruments which are responsive to beta radiation do no more than indicate its presence. However, correction factors can be applied to several types of instruments to allow a determination of beta-ray dose rates to an approximation sufficient for field work.

A number of survey instruments are insensitive to beta rays. This is true of all ionization-chamber instruments employing heavy walls. In practice a rough estimate of the beta dose rate can be made even with these instruments by multiplying the gamma dose rate by the beta-to-gamma dose-rate ratio for the geometry considered.

The beta-ray response of field survey instruments encountered under field conditions may be different from that under laboratory conditions. Scattering, such as that encountered in the case of gamma rays, may tend to lower the mean maximum energy of the beta rays. This tends to minimize the beta-ray hazard. However, until future tests determine mean maximum beta-ray energy, the necessity for measurement of beta-ray dose cannot be decided.

4.7 PROJECT 6.6, EVALUATION OF FILTER MATERIAL

4.7.1 Purpose

The objective of this project was to evaluate four types of standard and developmental filter materials used in individual- and collective-protective devices and one type of developmental filter material used for the sampling of air for particulate matter. These filter materials were evaluated against the contamination produced by the detonation of an atomic bomb and the contamination present in the resulting radioactive cloud. These filter materials were evaluated in multilayer pads at the standard flow-rate conditions used by the Chemical Corps in evaluation studies of filter materials. This permitted correlation of results with laboratory data.

4.7.2 Procedure

The filter materials were evaluated in eight drone aircraft in the first three tests at altitudes ranging from 16,000 to 30,000 ft. A portion of the cloud was continuously sampled iso-

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kinetically by a probe which extended through the nose of the aircraft. The sample of the cloud passed from the probe into a plenum chamber, from which it was continuously exhausted to the exterior of the aircraft. The filter materials were located on a suitable apparatus in the plenum chamber and evaluated against contaminated air drawn from the chamber.

Analysis of the filter materials was made by counting the gross beta activity collected on successive layers of the same filter material, and the efficiency of the material was calculated from the data obtained. Selected samples of the filter material were also counted to obtain a measure of the amount of alpha activity present in the cloud. Autoradiographs were made of selected samples to determine the distribution of activity on the filter papers. Decay data were also taken on selected samples to determine the gross decay constant for activity associated with particulate material in the cloud.

4.7.3 Results

The mean efficiency of the Chemical Corps types 6, 7, and 8 respiratory-protective filter material is 99.7 to 99.9 per cent against the gross particulate contamination. This is within the limits of accuracy of the methods used to determine efficiency. The mean efficiency of type 5 filter material is 84.1 per cent, and that of the polyfiber air-sampling filter material is 74.3 per cent. The average value for the gross decay constant was found to be −1.08 during the period H-hour plus 250 to 2000 hr.

4.7.4 Conclusions and Recommendations

The data obtained by this project correlate closely with laboratory data and indicate that the efficiency against a high-intensity radioactive aerosol cloud is comparable to that measured by a nonradioactive laboratory test aerosol. The data did indicate, however, that the presence of the high levels of radioactivity associated with the particulate matter in the cloud has no deleterious effect on the filtration properties of the respiratory filter materials evaluated.

4.8 PROJECT 6.7, CONTAMINATION AND DECONTAMINATION STUDIES

4.8.1 Purpose

The experiments conducted by this project were designed to yield information on surface contamination resulting from atomic bomb detonations, on the nature of contamination and decontamination processes, and on the extent of correlation between field and laboratory contamination and decontamination studies. The project comprised the following eight experimental investigations.

(a) Contaminability and Decontaminability of Materials. This experiment was designed to yield information concerning differences in contamination and decontamination characteristics of materials exposed to aerosol contamination in the field. The extent of correlation between the contamination and decontamination behavior of materials when exposed to an atomic cloud and when exposed to artificial contaminants was studied.

(b) Contamination and Decontamination Related to Surface Characteristics. The intent of this investigation was to determine whether the extent of contamination and/or ease of decontamination would correlate with any of four selected physical surface characteristics independently of the chemistry of the surfaces. The characteristics studied were roughness, porosity, dye rententivity, and the hydrophobic-hydrophilic nature of the surface.

(c) Industrial Decontamination Procedures. The purpose of this study was to test three general types of industrial-chemical cleaning methods for their ability to remove radioactive contamination.

(d) Evaluation of Decontamination Agents. The purpose of this experiment was to determine the efficiency of a number of decontaminating agents selected by type and applied in conjunction with mechanical brushing (performed by the Army Chemical Corps) and to determine the relative efficiency of a limited number of agents which had been studied previously in the laboratory (performed by USNRDL).

(e) Decontamination As a Function of Time. The objective of this investigation was to determine the efficiency of decontamination as a function of the time the contaminant remained on the surface.

(f) Influence of Prewetting on Decontamination Efficiency. This experiment was designed to determine whether the decontamination achieved on materials contaminated by aerosols

in the field is affected by wetting and drying the sample before decontamination is attempted.

(g) Fractionation of the Contaminant in the Atomic Cloud or in the Contaminating Process. The objective of this experiment was to determine the extent to which contaminants are either fractionated in the atomic cloud or in the process of deposition. Two methods of investigation, radiochemical analysis and decay measurement, were employed.

(h) Preferential Removal of Contaminant Species in Decontamination Operations. This study was designed to investigate possible fractionation of contaminant species in the process of decontamination. Two methods of investigation, radiochemical analysis and decay and absorption measurement, were utilized.

4.8.2 Procedure

Exposure of samples to radioactive contamination was accomplished by mounting 40 1-ft-square panels on the drone aircraft which were flown through the atomic cloud. The panels were 24-gauge anodized aluminum sheets upon which various coatings and samples were placed. Pressure sealing tape was used to fasten the panels to the underside of the wing and the upper side of the horizontal stabilizer. To each panel there was fastened a rip string which was tied to an aluminum loop. The rip string was placed beneath the tape on the leading edge of the panel in such a way that removal of the panels from the aircraft was accomplished by remote operation.

4.8.3 Results

(a) Contaminability and Decontaminability of Materials. Upon examination of materials in the laboratory, it was noted that frequently two adjacent samples of the same material exhibited great difference in initial contamination. Autoradiographic studies indicated that these differences were due to two factors: (1) accumulation of active particulates under and along the edges of the masking tape and (2) nonuniformity in distribution of the contaminant over the small sample surfaces.

The measurements of decontaminability of material revealed several interesting effects. Rough surfaces of glass and steel did not decontaminate nearly so well as smooth surfaces of glass and steel. No significant variation in decontaminability was observed among the rough surfaces.

(b) Contamination and Decontamination Related to Surface Characteristics. Results of the evaluation of surface characteristics were obtained for initial contamination, per cent decontamination, and residual contamination for the individual action and the interaction of surface characteristics. Materials appear to be most easily contaminated at the high porosities and become more difficult to contaminate at lower porosities. Surfaces seem to be more easily contaminated at high roughness and more difficult to contaminate at lower roughness. The angle of contact does not have a marked effect on contaminability. Materials appear to be more easily contaminated if their surfaces are dye retentive.

Materials are more easily decontaminated at the low porosities and become more difficult to decontaminate at the high porosities. Materials are more easily decontaminated at low surface roughness and become more difficult to decontaminate at high surface roughness. Decontamination is easier with surfaces having low contact angles and becomes more difficult at the high-contact-angle surfaces. Surfaces are more easily decontaminated when nonretentive as compared to retentive.

Mean residual contamination increases with the increase in porosity, roughness, contact angle, and dye retentiveness.

(c) Industrial Decontamination Procedures. Contrasting the results of the methods as such and not considering the additives, it was noted that, for the first cleaning, the hot-solution brushing proved most effective in the four surfaces studied. However, prolonged treatment with cold solutions gave cleaning efficiencies comparable to those obtained by use of hot solutions. The results would indicate that, knowing the decontamination efficiency of one of the methods on a surface, it is not possible to predict the decontamination efficiency of the method on another surface. The relative order of efficiency remained approximately the same for the surface tested.

(d) Evaluation of Decontamination Agents. Of the agents tested, the anionic types in general are the most efficient decontaminants. Nonionic type agents apparently show variable efficiency. Of the agents tested, Versene, Se-

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questrene AA, and Breeze are the most efficient decontaminants.

(e) Decontamination As a Function of Time. Consideration of the data derived on all materials exposed on the Dog, Easy, and George shots for the period of approximately 1 to 20 days indicates that no conclusions may be drawn regarding the influence of time during this period. The data derived were contradictory; increases and decreases in decontamination efficiencies appear for the same periods on different samples.

(f) Influence of Prewetting on Decontamination Efficiency. The results of this investigation are consistent with the idea that there is a decrease in decontamination efficiency when aerosol-contaminated surfaces are wetted and dried before decontamination. However, contamination and decontamination values obtained on duplicate samples are fairly divergent, and it is felt that the data are not conclusive.

(g) Fractionation of the Contaminant in the Atomic Cloud or in the Contaminating Process. Data obtained in this study indicate that the composition of contaminants retained on surfaces of aircraft is not identical at all altitudes. It does not, of course, distinguish between fractionation in the contaminating event or differences in the composition of the contaminant at various altitudes. Since the latter effect is known to occur, one may expect it to account for at least a portion of the observed fractionation.

(h) Preferential Removal of Contaminant Species in Decontamination Operations. Preferential removal of contaminant species did occur in the decontamination process. Preferential removal was also indicated by the results of the radioactive-decay-rate studies.

4.8.4 Conclusions

Appreciable differences were noted in the amounts of contamination found on the various materials exposed on drone aircraft. However, the physical condition of the surfaces, the way in which they were exposed, and perhaps other factors had a profound effect on both the levels of contamination and the extent of decontamination achieved and frequently appeared to be controlling factors. A correlation between surface roughness (and to a lesser extent porosity and dye retentivity) and the contamination and decontamination properties of surfaces was established for this type of contaminating event. The information obtained in this study is considered to be of value in specifying materials for military purposes in radiological defense.

Data on the use of common industrial cleaning methods and agents indicate that these methods and agents also are effective in radiological decontamination. The military use of industrial methods for decontaminating is suggested.

Studies of chemical agents as decontaminants have assisted in the selection of efficient agents for field use. They have also provided valuable information on the chemical nature of substances which act as efficient decontaminating agents. The use of laboratory tests to predict field behavior of decontaminating agents has been supported by the results of the studies on decontaminants.

Measurable decreases in decontamination efficiency appeared with increased time of standing before decontamination. The effect is not considered to be operationally important, however, for this type of contaminating event for short times such as a few days after contamination.

The effect of wetting and drying a contaminated surface before decontamination was found to be sufficiently small so that it is not likely to be of operational significance. The distinctive nature of the contaminating event precludes generalization of the conclusion to other types of bursts in which the effect is predicted to be more important.

The heterogeneous nature of the contaminant deposited on drone-aircraft surfaces was confirmed. Gross decay rates should be considered as falling within a range of decay rates rather than being represented by a single rate.

The preferential removal of contaminant species as a result of a decontamination operation was demonstrated. Alteration of decay rates as a result of decontamination is not of greater magnitude than the alteration of rates observed at various times after fission and is often of lesser magnitude.

4.9 PROJECT 6.8, CLOUD RADIATION FIELD

4.9.1 Purpose

The object of this study was to measure the relation between the spatial distribution of the radioactive fission products and the resultant radioactive field in an atomic bomb cloud. The

results from this project were intended to (1) determine the radiation intensity within the atomic bomb cloud, (2) correlate this intensity with the fission-product particulate boundary of the cloud as defined by the jet impactor, (3) resolve the manner in which this radiation intensity fluctuates in relation to the distribution of radioactive particles, and (4) give the relation that these effects bear to the visible boundary of the cloud.

4.9.2 Procedure

Project 6.8 participated in Dog, Easy, and George shots. In all three shots the basic plan was to have eight drone aircraft fly through the cloud, one each at the even-numbered thousand-foot altitudes from 16,000 to 30,000 ft. Each drone was to make at least two passes through the cloud, the second pass being at a heading of 180° from the first. The pattern for the release of these drones by the controlling aircraft was to bring them over the target 210 sec after detonation for the first two shots and 300 sec after detonation for the third shot. Each aircraft was equipped with two recording type gamma-ray-intensity—measuring instruments, the first covering the range 0.1 to 20,000 mr/hr and the second measuring from 1 to 1,000,000 r/hr in order to plot the radiation-intensity distribution outside and within the atomic cloud. The data thus obtained recorded radiation intensity as a function of time after zero hour.

4.9.3 Results

The results of the cloud-approach data indicate that the general value for the increase in the radiation rate when approaching the cloud lies between 10 and 20 per cent per second for aircraft flying at air speeds between 100 and 150 yd/sec. The erratic behavior of the low-intensity rate meters under the extreme conditions encountered at the site allowed the use of only 50 per cent of the data obtained.

The high-intensity rate meters appeared to function more reliably than did the low, with results being obtained in 87 per cent of the possible cases. A summary of the average radiation within the cloud on the first pass of the aircraft, as defined by the rate meter and the jet impactor, is given as follows: Dog shot, 12,400 r/hr; Easy shot, 10,900 r/hr; and George shot, 4560 r/hr. The second-pass averages for each shot were 790 r/hr; 1550 r/hr; and 800 r/hr, respectively.

Although one of the original objectives of this project was the determination of the correlation, if any exists, between the visible cloud and the fission-particle cloud, there is no evidence other than the cloud entry and exit times upon which to base any definite conclusions.

4.9.4 Conclusions

The cloud-approach data seem to indicate that no general value can be assigned for the exact rate of change of the radiation intensity on approaching an atomic cloud since the figure appears to depend on the size of the bomb, the shape of the cloud (which is determined by the atmospheric conditions prevailing as well as the kilotonnage of the bomb), the speed of approach of the plane, and the time at which the approach is made. Insufficient data for any one shot preclude any conclusions at this time other than an order of magnitude of the rate of change.

The high-intensity rate meter data concerning the radiation rate are equally void of any definite trends as to the variation of the radiation as a function of altitude, except that it appears that the earlier the entrance into the cloud the greater will be the intensity measurement. This can also be surmised from the decay of fission products. If it were possible to test the same size bomb on separate occasions, or different bombs at comparable altitudes at comparable times, some conclusions might be justified. A general statement that appears to hold is that the radiation intensity measured is dependent on the concentration of the fission particles present. This would suggest that the intensity measure would vary inversely with the kilotonnage of the bomb for times within a half hour or so after detonation.

One fairly obvious conclusion is that the relative energy of the gamma-ray cloud is fairly low, being of the order of 200 kev. This is based on the general correlation between the concentration of the fission particles and the relative spacing between the puffs in the cloud, with the corresponding radiation intensity.

The distinct correlation between the radiation rate and the density of the autoradiograph (as an indication of the density of the fission-particle cloud) indicates that the rising atomic bomb cloud, at the altitudes examined, is, for the first 3 or 4 min, similar to a chimney with puffs of smoke rising in it. The breakdown of this chimney effect becomes apparent with the plateau-like appearance of the second pass (approxi-

mately 10 min after detonation) and the third pass for Easy shot. This latter pass also gives an indication of the breakdown of the cloud as an entity, with the spreading out of the radioactive particles becoming more apparent.

Although the cloud entry times may be indicative of the relative placements of the visible cloud and the fission-product particulate cloud, they cannot be considered conclusive because of the inherent inaccuracies of the timing of the cloud entrance and exit by the navigator or his assistant aboard the controlling aircraft. Further evidence similar to that offered by photographs taken of the growth and the rate of rise of the cloud is essential before it can be definitely said that the visible cloud is larger than the fission-particle cloud.

4.10 PROJECT 6.9, PROTECTIVE CLOTHING AND CLOTHING AND PERSONNEL DECONTAMINATION

4.10.1 Purpose

There were three phases to this project, as indicated by its title. The phases and the objectives of each were as follows:

1. Protective clothing. This included (1) comparison of the relative contaminability and decontaminability of selected test fabrics and materials and (2) evaluation of the hazard due to the shaking off of contaminating materials from test fabrics following contamination.
2. Clothing decontamination. This included (1) testing of methods and materials for the decontamination of clothing, (2) training of personnel under field conditions in the handling and decontamination of clothing using Quartermaster Corps laundry equipment, (3) evaluation of experimental monitoring equipment and development of a practical clothing-monitoring procedure, and (4) gathering of information for inclusion in technical manuals.
3. Personnel decontamination. This included (1) testing of proposed materials for the decontamination of personnel, (2) evaluation of the requirements for personnel-monitoring equipment and development of proposed monitoring procedure for field operations, and (3) development of field decontamination procedures for personnel radioactively contaminated.

4.10.2 Procedure

1. Protective clothing. The contaminability and decontaminability of clothing materials and hazards incident thereto were evaluated by exposure of the materials to contaminating conditions, monitoring, decontamination and remonitoring, and observation of related conditions. Susceptibility of the various materials to contamination was tested by exposure to contamination by actual wear under operating conditions and by controlled contamination such as dragging materials through contaminated areas and drumming (placing materials and contaminated soil in a rotating drum). Monitoring of the clothing and test materials evaluated was accomplished by use of the Chemical Corps clothing checker, the Signal Corps table-top and wringer clothing checkers, the portable G-M survey meter AN/PDR-27A, and a liquid decontamination device. For control purposes the Chemical Corps clothing checker with scaler was used. Background was read frequently and recorded, and activity readings on samples were corrected accordingly.
2. Clothing decontamination. The contaminated swatches, test clothing, and Rad-Safe clothing were collected as they became available and were monitored on one or more of the clothing checkers (the instruments used were the same as for the first phase above). After monitoring, the contaminated items were separated as either high- or low-activity lots based on a preliminary check. Lots were then given a decontamination laundering using the formula modification under investigation or that which was required in order to permit comparison of test-materials characteristics. Following this operation, the garments and samples were remonitored. To assist in the evaluation of the effectiveness of each step in the laundry decontamination formulas, pH measurements and activity readings were taken on samples of each wash solution by means of a special pet cock installed in the washer shell. A standard WW II type Quartermaster Corps mobile laundry was used for all decontamination purposes.
3. Personnel decontamination. Personnel returning from contaminated areas were monitored at the project area. Monitoring instruments included various types of survey meters and a Chemical Corps clothing checker with an auxiliary hand and arm guide. Clothing, while still on the individual, was monitored first. The individual then removed the clothing and was remonitored. Particular care was taken to survey the eyes, hair, and fingernails since those areas showed a particular affinity for contaminants. Showers were provided for those personnel

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whose skin became contaminated. Various types of soaps and detergents were used.

In addition to the personnel exposed to contamination in the course of their duties, project personnel participated in controlled contamination and decontamination. In this test each man contaminated his hands and arms up to the elbow by rubbing contaminated soil onto the skin. A check of the contamination was made using a survey meter. Paper sleeves were then pulled over the hands and arms to prevent instrument contamination, and the man was monitored using the Chemical Corps clothing checker with scaler. The activity of the sleeves was then counted, and the difference, corrected for background, was recorded. Each man then washed in a pail of distilled water, using one of the test detergents. Fresh paper sleeves were donned, the monitoring procedure was repeated, and the count was recorded. After three washing and monitoring cycles, each man recontaminated himself and repeated the entire procedure until each test detergent had been used by five different men. Five other men followed the same process, except that they washed in plain fresh water without the aid of a detergent.

4.10.3 Results

1. Protective clothing. The planned dependence on operational wear of test clothing and on the dragging of the test-material swatches in contaminated areas proved inadequate for the evaluation of the relative contaminability of materials to determine their relative decontaminability. Drumming was the principal means of contamination used for comparison of the swatches; however, sufficient test garments were similarly contaminated to verify the validity of the drumming procedure. Sufficient data on actual operation-wear contaminability of test garments were obtained to similarly validate the controlled contamination by drumming. The relative decontaminability results for the drummed samples were also verified by comparison with the decontaminability of test clothing worn.

2. Clothing decontamination. Clothing and test materials contaminated by atomic detonations were successfully decontaminated. The types of radioactive materials removed were soil pickup on the shot islands from the areas directly contaminated by the burst, fall-out pickup from soil and vegetation on contaminated islands, and cloud materials which adhered to the planes flown into the atomic-burst cloud. The laundering formula developed during preliminary test operations was found to be more than adequate, and a shortened version was used mainly in this project. No contamination of the laundry equipment occurred.

3. Personnel decontamination. Personnel contaminated in the course of their duties were usually able to remove contamination in 8 to 10 min by showering, although some cases required up to 25 min to remove contaminants. Various soaps were used, and there was no significant difference noted in their effectiveness.

The level of contamination of hands and arms of the project personnel participating in the controlled test averaged between 15 and 20 mr/hr as measured with a survey meter. The net counts at the time the men began their decontamination washing averaged 160,235 counts/min with a range from 60,000 to 273,400 counts/min. All detergents used, including two toilet soaps, removed in excess of 99.2 per cent in three washes. Control trials using plain distilled water showed less decontamination at each stage of the test, but after three washings they showed 97.4 per cent removal of contamination.

4.10.4 Conclusions

1. Protective clothing. All materials evaluated in this phase were found to be readily decontaminable to well below the tolerance level of 7 mr/hr at 6 in. using the AN/PDR-5 survey meter. The differences in contaminability and decontaminability of the materials tested were small except for water-repellent finished cotton and FWWMR (fire-, wind-, weather-, mildew-resistant) treated cotton duck. The nature of the fiber affects the pickup in lightweight fabrics, but it does not affect the decontaminability of launderable textile materials.

With reference to the shake-off hazard, it appears that the handling of contaminated clothing may constitute an inhalation hazard depending on the ventilation, the degree of shake-off, and the particle size. Contaminated clothing should be handled dry only under well-ventilated conditions unless respiratory-tract protectors are used.

Further testing is needed in this area to further evaluate the effects of water-repellent finishes on contaminability and decontaminability of textiles. Also, particle size of air-borne

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contaminants incident to the handling of contaminated clothing should be determined in order to evaluate the hazard of inhalation.

2. Clothing decontamination. The results of the test of laundering methods and materials for the decontamination of contaminated clothing were highly satisfactory. It was found that decontamination by laundering is practical regardless of whether the contamination is from the immediate area of the explosion, from the cloud, or picked up from fall-out. Practical laundering decontamination formulas were developed and proved as to their efficiency, one (Formula 77) for a high degree of contamination and one (Formula 77A) for a moderately high contamination.

It was proved that the Quartermaster Corps mobile field laundry can satisfactorily decontaminate launderable clothing and, using the formulas developed, can reduce the contamination level of clothing worn by personnel in the field to below the tolerance level recommended by the Armed Forces Special Weapons Project.

Further testing and analysis are required (1) to determine the adequacy of decontamination formulas under other conditions of contamination, (2) to define inhalation tolerances and to evaluate dust hazards in the handling of contaminated clothing, and (3) to define tolerance levels for the wearing of radioactively contaminated clothing with particular reference to limited areas of moderate to high contamination in order to establish both the monitoring procedures and the decontamination levels to be followed.

The monitoring instruments used were found to be inefficient for the monitoring of clothing in support of a laundering decontamination operation. Large-area multiple-tube instruments are required for test operations. A survey type meter with a wide range of intensity, a large area probe, and a quick response appears to be appropriate for the field monitoring of clothing.

3. Personnel decontamination. Although the data obtained from personnel monitoring and decontamination operations were not as complete as had been hoped, sufficient information was secured to permit drawing certain conclusions.

The monitoring of personnel showed that hairy regions of the body are more prone to contamination than other areas; however, the extent to which this occurs is dependent upon the amount of oil and perspiration present on the skin. Decontamination showering is effective and will decontaminate personnel to the tolerance level or below when aided by the use of commercial soaps suitable for the type water used. It was further established that no special detergents incorporating chelating agents are necessary to effectively decontaminate body surfaces; the standard field-issue Army toilet soap is adequate. Further testing is necessary, however, to determine the effectiveness of ordinary fatty-acid toilet soaps when used with hard water.

The unusual conditions offered by the shot series gave ample opportunity to field-test the usability of survey instruments and to develop procedures and ideas to facilitate field monitoring. It was determined that monitoring of personnel for either garment or skin contamination in the presence of high background cannot be accomplished accurately by use of current type G-M survey meters. In the presence of high background the ion-chamber instrument proved successful for monitoring personnel when specialized measures were taken to hold the background steady. Further development of survey instruments is needed to facilitate the monitoring of large numbers of personnel.

4.11 PROJECT 6.10, EVALUATION OF COLLECTIVE-PROTECTOR EQUIPMENT

4.11.1 Purpose

The object of this experiment was to provide an assay of Chemical Corps collective-protection equipment under the conditions of an atomic detonation. In Operation Sandstone, the structure containing the collective protector was overturned and, although the collective protector was undamaged, no assay of performance could be made.

4.11.2 Procedure

The protected shelter, located 1710 ft from Ground Zero, was a reinforced-concrete structure designed by the Corps of Engineers. A positive pressure of filtered air was maintained within the shelter by means of the collective protector. Antiblast closures were installed at the shelter inlet and exhaust to prevent a dangerous pressure build-up within the structure. The filtered-air stream of the collective protector was continuously monitored for beta-gamma activity. Air samples were collected continuously from various sampling points within the shelter and were drawn through a filter pad to obtain a measure of the particulate activity entering the shelter. Film badges were

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installed at various points within the shelter to provide a measure of total integrated gamma dosages at these locations. Temperature-sensitive-paint panels were installed within the shelter to determine the temperature rise within the shelter due to the thermal radiation of the burst. Pressure instrumentation of the shelter was made to determine any blast-incurred increase in internal shelter pressure. A gasoline-operated electric generator was utilized to supply electrical power for the shelter of electrical equipment in the event of central power failure.

The field antiblast-closure installations were utilized to determine the operating efficiency of this unit through a range of activating overpressures. A collective protector, less motor-blower, was emplaced in the ground near the shelter location. This unit was not protected from the effects of blast as compared to the protected installations in the shelter.

4.11.3 Results

There was no functional damage to the shelter or to any of the installed equipment within the structure resulting from the blast. Pressure and temperature increases within the shelter due to the burst were negligible.

The indicated radiation level within the shelter closely approximated that which could be expected from the direct radiation alone. The radiation records within the shelter were fragmentary because of the failure of the emergency power system. The record for one of the G-M tubes installed in the collective-protector air stream indicated a 13,200 counts/min peak during the prompt-radiation period. A record of the second tube installed in the air stream went off scale (2000 counts/min scale limit) but immediately returned to a level of 200 counts/min, which it maintained until the record terminated 5 min after the detonation. The third record, which indicated background activity only, ended during the prompt-radiation period and gave no useful data.

The antiblast closures functioned adequately at the shelter. Protected-side pressures of 12.6 psi or less were measured in the field antiblast-closure installations located from 300 to 2500 yd from Ground Zero.

The unprotected collective-protector-equipment installation was unruptured, but it showed evidence of damage to the surface of the filter material resulting from the action of high-velocity sand impingement.

4.11.4 Conclusions

As a result of the data obtained, it has been determined that complete protection for personnel and equipment from an atomic detonation is feasible in a protected-shelter installation of the type used in this project. The scope of the project was limited because only a single structure was available for instrumentation. This condition precluded the installation of control instrumentation in an unprotected shelter. Consequently, the results of this test indicate the resultant conditions in a protected shelter, but they do not present direct competitive evidence of the extent of hazard to be expected in an unprotected installation. Further work is necessary to more fully assess the degree of hazard present under various conditions of detonation.

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Chapter 5

Program 8, Aircraft Damage and Radio, Radar, and Photographic Studies

5.1 PROJECT 8.1, EFFECTS ON AIRCRAFT

This project was conducted for the purpose of obtaining factual data on blast, gust, and temperature effects of an atomic explosion on aircraft in flight. Special instrumentation for measurement of the above effects was installed in Air Force airplanes and flown at predetermined altitudes and distances from the zero point of the explosion. These distances were based on the predicted yields of the shots scheduled. Complete analysis of the data received is now under way at AMC; therefore only preliminary results or indications are available at this time.

The following sections give a short résumé of the participation of this project.

5.1.1 Dog Shot

One T-33 jet drone, one B-17 drone, two manned B-50D's, and one manned XB-47 participated in the test. Distances at shot time from zero point were from 9260 ft (T-33 drone) out to 52,100 ft to the farthest airplane (B-50D). Distances at shock-arrival time were from 11,000 ft (T-33 drone) out to 40,900 ft to the farthest airplane (B-50D). Altitudes varied from 7800 ft (T-33) to 29,000 ft (B-50D).

No structural damage resulted on any of the airplanes. Damage due to heat was obtained on the T-33 drone and a B-17 drone at 15,000 ft altitude and 16,150 ft slant range. The T-33, which is all-metal construction, had scorched paint in several places. On the B-17 the fabric surfaces on the underside of the ailerons and elevators were burned away, and paint was scorched in several other places. Black paint was predominantly affected.

The crew of the XB-47 at 25,700 ft slant range reported feeling considerable heat; however, the heat was not unbearable, and there were no aftereffects.

Recordings on the specialized instrumentation were successfully accomplished, and a qualitative analysis appears in Annex 8.0, WT-34.

5.1.2 Easy Shot

Based on Dog shot results, one each of the T-33 drones and B-17 drones was positioned to receive blast loads in excess of 90 per cent of the ultimate designed load factor of the aircraft.

Two T-33 drones, two B-17 drones, one manned XB-47, and two manned B-50D airplanes participated in the test. Distances at shot time were from 6540 ft (T-33) to 38,000 ft to the farthest airplane (XB-47). Distances at shock-arrival time were from 6920 ft (T-33) to 33,000 ft (XB-47). Altitudes varied from 6500 ft to 33,000 ft.

The low T-33 went out of control shortly after shock-arrival time and crashed in the ocean. The cause could not be established. Owing to an inoperative telemetering system, no data were obtained.

The fabric surfaces of the low B-17 drones (11,000 ft altitude) had been covered with aluminum foil, a good reflective surface, and although heat was high (over 200°F) no major damage to these surfaces resulted. Considerable damage was apparent to painted sections, and one tire was burned to the extent that it blew out on landing. Structural damage was done to the airplane but not to the extent that it was unflyable. After complete inspection it was

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considered safe to fly to the ZI with mini[illegible] load aboard. The airplane was returned to AMC for detailed inspection.

The other B-17 drone (12,000 ft altitude) went through the top of the "puff" of the cloud. Minor structural damage was done.

There was no structural damage on the manned airplanes and no reported abnormal heat from the explosion.

5.1.3 George Shot

Owing to inclement weather it was decided just prior to take-off time to fly all drones as manned airplanes. Positions were changed to much greater distances for crew safety. Participating in this shot were one T-33, three B-17's, and the two B-50D's. Heavy rain at Kwajalein prevented the XB-47 from taking off.

No structural damage was suffered on any of the airplanes. Several crews reported noticeable heat, but for the distances involved this heat was not excessive.

5.1.4 Comments

All data were returned to AMC for reduction, and analysis was accomplished there and at the Massachusetts Institute of Technology on blast and gust effects. Thermal-effects studies will be conducted at UCLA, which is under contract to the Air Force for both theoretical and factual studies of the problem.

The following indications, to be used as tentative data only until complete analyses can be made, were derived from preliminary scanning of the data obtained.

1. Blast and gust. The previous safety factor of $\frac{1}{4}$ psi overpressure for operational aircraft was definitely proved low. One pound overpressure is much more realistic, and it is believed that the Air Force aerodynamists will be able to establish safe limits for each type of airplane as a result of these tests. Safe gust velocities which an airplane can withstand vary with speed and altitude. Safe operating altitudes and speeds based on bomb yields will be established by AMC as a result of these tests.
2. Thermal radiation. As bomb yields increase, the thermal problem also increases. These were the first tests in which factual data were obtained. It is evident that, if operational aircraft are to operate up to safe limits on blast and gust, protection will have to be given to the crew; also, consideration will have to be given to portions of the airplane which might be affected by heat, i.e., fabric surfaces, paint, etc. The Air Force should continue its thermal-effects studies and take corrective action in the design of aircraft.
3. Radioactive radiation. In light of the distances from atomic explosions that aircraft must be to be safe from blast and thermal effects, the effects of radioactive radiation appear to be no hazard. This is being considered in the Air Force studies.

On the subject of instrumentation the following suggestions are made:

1. There should be further development of high-speed recorders. The Webster-Chicago recorders used required excessive maintenance, calibration, and adjustment and had questionable reliability.
2. The telemetering system furnished by Melpar failed completely on all tests. This definitely limited the positioning of drones, and a portion of desired data was lost. A system for use at longer distances (in excess of 100 miles) and a high degree of reliability should be developed.
3. The MSQ-1 radar used for remote-control system for drones gave very good results; however, it was expensive and highly complex and required a large number of personnel to maintain and operate it. A simpler system with a high degree of reliability and requiring a minimum of personnel should be developed. Investigation of automatic Shoran techniques is suggested.

It is recommended that this type of project (effects on aircraft in flight) be included in future atomic test programs, with consideration being given to using manned aircraft of current tactical design. The number of participating aircraft could be reduced under this proposal. Telemetering of data is not recommended until further development of existing equipment is accomplished. High-speed oscillographic records are recommended.

5.2 PROJECT 8.2A, EFFECTS ON AIRCRAFT (GROUND) — EASY SHOT

The object of this test was to place specified aircraft components at varying distances from 4000 to 16,000 ft from the detonation point and, under carefully controlled conditions, measure and evaluate the effects of the blast and heat on these structural components.

These structural components [redacted] conventional aircraft parts such [redacted] fuselage, an F-47 wing, etc.; vente[redacted]n-vented airfoils; and specially designed rigid- and swept-wing airfoils. Measurements of air loads, air pressure, structural movement, and heat were made.

The results of this test under static conditions will be correlated with those of Project 8.1 under dynamic conditions to check as to whether ground tests may be utilized in the future to obtain much of the needed information pertaining to blast effects on aircraft structures.

Four identical test installations were made on the islands of Engebi, Muzin, Teiteiripucchi, and Bokonaarappu. Results on all test sites appear satisfactory, and the analysis of data appears in Annex 8.2A, WT-65. From visual inspection it appeared that the loads and pressures reacted on the exposed models in the way predicted by the theoretical studies, indicating a remarkable correlation. No definite conclusions or recommendations can be made at this time.

5.3 PROJECT 8.2B, INTERFEROMETER GAUGES

The object of this test was to obtain pressure-vs-time data at test-site locations of Project 8.2A and to test this new type of pressure gauge commonly referred to as the "Buck" gauge. This gauge utilizes the principle of the interference bands of light produced on the mirrored surfaces of a quartz diaphragm. As the pressure on the diaphragm varies the thickness of the film of air, which separates the plates, the interference fringes are displaced, giving a direct measurement of the pressure.

This gauge is simple to operate, is inexpensive, requires a minimum of personnel, and gave highly satisfactory operation. Four gauges were installed at each 8.2A site. Reduction of data and plotting of curves were accomplished within 48 hr after the shot.

The gauge itself proved satisfactory and will be valuable instrumentation for future tests. On shots other than Easy, the gauges and personnel were included in Program 1.

5.4 PROJECT 8.3A, RADAR-SCOPE PHOTOGRAPHY

The object of this test was to obtain photographs of radar scopes during the atomic ex[redacted] analysis and evaluation as a method [redacted]ng bombing accuracy and estimating [redacted]age. Pictures were taken of A and B scopes of the APQ-24 radars on the two B-50D's of Project 8.1 for Dog, Easy, and George shots.

During Operation Greenhouse it was conclusively proved that, under the conditions which existed at the Eniwetok Atoll during that time period, detonations of relatively high-yield atomic explosions were easily detected and displayed on the scope of an X-band radar system. It was found possible to locate Ground Zero to an accuracy of approximately 500 ft.

It is recommended that similar tests be conducted over land areas with equipment designed on the basis of data obtained during Greenhouse.

5.5 PROJECT 8.3B, MEASUREMENT OF EFFECTS OF ATOMIC EXPLOSIONS ON RADIO PROPAGATION

The object of this test was to find what effects, if any, occur to the transmission and reception of radar and radio waves, both direct and reflected, during and after an atomic explosion. Possible sources which might have effects are blast, radiation, or ionization. These tests were conducted on Dog, Easy, and George shots.

Both short-range (within the atoll area) and long-range (as far as Japan and Hawaii) radios were monitored by recorders. Also, the National Bureau of Standards (NBS) made ionosphere studies with their standard equipment.

All equipment operated satisfactorily, and data were being analyzed and evaluated by the Signal Corps and NBS at the time of writing. It appears from early evaluation of the data that there is no appreciable effect on radio propagation due to radiation from the detonation of an atomic weapon.

5.6 PROJECT 8.3C, AERIAL PHOTOGRAPHIC DAMAGE STUDY

The object of this test was to check photographic interpretation of damage against actual damage done by an atomic explosion. This was accomplished by taking photographs, both vertical and oblique, of the main structures of Program 3 before, during, and after Easy shot. The photographic missions were accomplished with apparent satisfactory operation of equip-

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ment. All photographs have been processed and forwarded to the Intelligence Branch, Headquarters, United States Air Force, for analysis and evaluation.

5.7 PROJECT 8.3D, FILM-FOGGING STUDIES — GEORGE SHOT

This project was on George shot only but was a fairly comprehensive survey of the effects of film fogging as a function of dosage. The film was all aerial film of Air Force types N and L and was exposed to radiation under assimilated operational conditions. Loaded A-5A magazines were placed at four similar stations in the Strategic Air Command (SAC) RB-29 and the two AFOAT-1 WB-29 aircraft. Two magazines were placed in each of the AEC drones, one in the bomb bay and one in the radio compartment. Ten magazines were placed on the ground on Rojoa, with each film type represented at five locations.

The very early information on the film that has been developed indicates that the film density (fogging) increases with the dosage, that in the lower dosage levels the readability of the film is good, and that type L film is more dense than type N film for an equal dosage. However, type N film shows more mottling. It is indicated also that there is more random fogging on film carried in bomb bays and unpressurized or unsealed compartments, probably due to particulate contamination. The dosage range is from about 0.5 r to greater than 100 r. The final Greenhouse report covers not only the complete results of the SAC experiment but also correlates the results with other film-fogging studies made by the Los Alamos Scientific Laboratory.

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AEC, Oak Ridge, Tenn., W23150

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